

General Relativistic Considerations of the Field Shedding Model of Fast Radio Bursts

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ABSTRACT

Popular models of fast radio bursts (FRBs) involve the gravitational collapse of neutron star progenitors to black holes. It has been proposed that the shedding of the strong neutron star magnetic field (B) during the collapse is the power source for the radio emission. Previously, these models have utilized the simplicity of the Schwarzschild metric which has the restriction that the magnetic flux is magnetic “hair” that must be shed before final collapse. But, neutron stars have angular momentum and charge and a fully relativistic Kerr Newman solution exists in which B has its source inside of the event horizon. In this letter, we consider the magnetic flux to be shed as a consequence of the electric discharge of a metastable collapsed state of a Kerr Newman black hole. It has also been argued that the shedding model will not operate due to pair creation. By considering the pulsar death line, we find that for a neutron star with $B = 10^{11} - 10^{13}$ G and a long rotation period, > 1 s this is not a concern. We also discuss the observational evidence supporting the plausibility of magnetic flux shedding models of FRBs that are spawned from rapidly rotating progenitors.

Key words: Black hole physics — X-rays: binaries — accretion, accretion disks

1 INTRODUCTION

Fast radio bursts (FRBs) are a new kind of astrophysical transient that is of unknown origin. First discovered in Lorimer et al. (2007), it was later found that the distribution lies primarily well above the Galactic plane. Combined with a large dispersion measure indicates a celestial origin and large distances corresponding to redshifts, $0.5 < z < 1$ (Thornton et al. 2013). The radio bursts durations are on the order of milliseconds with a radio luminosity of $10^{38} - 10^{40}$ ergs (Zhang 2014). The space density is large, 10^{-3} gal $^{-1}$ yr $^{-1}$ compared to gamma ray bursts (GRBs), a factor of 1000 larger (Zhang 2014). Light travel time arguments based on 1 msec imply that the emission region is very compact, less than 20 times a neutron star (NS) radius or 30 times the diameter of a black hole (BH) of a few solar masses. This inspired the “blitzar” model of FRBs that is based on NS collapse to a BH, Falcke and Rezzolla (2014), that was later adapted to the work of Zhang (2014). The models begin with a supramassive NS that is marginally supported by centrifugal force. During the collapse, the magnetic “hair” is released, the so-called “no hair theorem.” This is the mag-

netic energy source for the FRB in the model. It has been largely forgotten, but the model of shedding magnetic hair was originally proposed to explain GRBs (Hanami 1997).

This letter is concerned with the two fundamental physical points of concern for the model. Firstly, previous FRB models have considered a Schwarzschild metric. With this restriction, the magnetic field cannot have its source within the black hole and the field is considered magnetic hair that needs to shed during the collapse. In reality, there is angular momentum and charge and the Kerr-Newmann solution (a charged rotating black hole, KNBH hereafter) allows for a magnetic field that has its source inside the event horizon. The neutron star is charged and rotating, so is the black hole. The second issue is the notion that the magnetic flux might not be released since pair creation in the magnetosphere might self-sustain the field even after collapse (Lyutikov and McKinney 2011). We find an interpretation involving a progenitor NS beyond the “pulsar death line” and electric discharge of a meta-stable KNBH intermediate state that allows the magnetic field shedding model of FRBs to proceed regardless of these concerns. Heavy dead

pulsars may require centrifugal force to be supported against gravitational collapse. We argue that the torque down of dead pulsars could initiate collapse with a space density consistent with the FRB space density. We also comment on whether a supramassive rapidly rotating NS can collapse to form a meta-stable KNBH.

2 THE KERR-NEWMAN FIELD ENERGY

The magnetic field energy responsible for the FRB was calculated outside a NS in the Newtonian approximation (Zhang 2014). In this section, we calculate the magnetic field energy and the electric field energy in the Kerr-Newman spacetime that represents a rotating charged black hole with a net magnetic flux through each hemisphere. The axisymmetric, time stationary spacetime metric is uniquely determined by three quantities, M , a and Q , the mass, angular momentum per unit mass, and the charge of the hole respectively. In Boyer–Lindquist coordinates the metric, $g_{\mu\nu}$, is given by the line element in geometrized units

$$\begin{aligned} ds^2 \equiv g_{\mu\nu} dx^\mu dx^\nu = & - \left(1 - \frac{2Mr - Q^2}{\Sigma} \right) dt^2 + \Sigma d\theta^2 \\ & + \left(\frac{\Sigma}{\Delta} \right) dr^2 - \frac{(4Mr - 2Q^2)a}{\Sigma} \sin^2 \theta d\phi dt \\ & + \left[(r^2 + a^2) + \frac{(2Mr - Q^2)a^2}{\Sigma} \sin^2 \theta \right] \sin^2 \theta d\phi^2, \end{aligned} \quad (1)$$

where $\Sigma = r^2 + a^2 \cos^2 \theta$ and

$$\Delta = r^2 - 2Mr + a^2 + Q^2 \equiv (r - r_+)(r - r_-). \quad (2)$$

There are two event horizons given by the roots of the equation $\Delta = 0$. The outer horizon at r_+ is of physical interest

$$r_+ = M + \sqrt{M^2 - Q^2 - a^2}. \quad (3)$$

We choose to simplify our calculations by computing quantities in a hypersurface orthogonal, orthonormal frame. A natural orthonormal frame associated with Zero Angular Momentum Observers (ZAMO) (who are also locally non-rotating) can be used to express, locally, the electromagnetic field in terms of electric and magnetic (observer-dependent) fields. Being hypersurface orthogonal (i.e., vorticity-free), the ZAMO frame gives an unambiguous definition of the field that is integrable (Punsly 2008). The basis covectors are

$$\begin{aligned} \omega^{\hat{0}} &= 1/\sqrt{-g^{tt}} dt, \quad \omega^{\hat{r}} = \sqrt{g^{rr}} dr, \\ \omega^{\hat{\theta}} &= \sqrt{g^{\theta\theta}} d\theta, \quad \omega^{\hat{\phi}} = \sqrt{g^{\phi\phi}} d\phi. \end{aligned} \quad (4)$$

Due to the long expressions to follow, it is worthwhile to abbreviate the notation for $(\sin \theta, \cos \theta)$ as (s, c) , i.e. $\Sigma = r^2 + a^2 c^2$.

In the ZAMO basis, the Kerr-Newman electric and magnetic fields are

$$E(n)_{\hat{r}} = + \frac{Q(r^2 + a^2)(r^2 - a^2 c^2)}{\Sigma^2 \sqrt{(r^2 + a^2)^2 - a^2 s^2 \Delta}}$$

$$\begin{aligned} E(n)_{\hat{\theta}} &= - \frac{2Qra^2 s c \sqrt{\Delta}}{\Sigma^2 \sqrt{(r^2 + a^2)^2 - a^2 s^2 \Delta}} \\ B(n)_{\hat{r}} &= - \frac{2arcQ(r^2 + a^2)}{\Sigma^2 \sqrt{(r^2 + a^2)^2 - a^2 s^2 \Delta}} \\ B(n)_{\hat{\theta}} &= - \frac{aQs\sqrt{\Delta}(r^2 - a^2 c^2)}{\Sigma^2 \sqrt{(r^2 + a^2)^2 - a^2 s^2 \Delta}}. \end{aligned} \quad (5)$$

The associated electromagnetic invariants are

$$\begin{aligned} \mathcal{I}_1 &= [E(n)]^2 - [B(n)]^2 = Q^2 \frac{(r^2 - 2rac - a^2 c^2)(r^2 + 2rac - a^2 c^2)}{\Sigma^4} \\ \mathcal{I}_2 &= E(n) \cdot B(n) = -Q^2 \frac{2arc(r^2 - a^2 c^2)}{\Sigma^4}. \end{aligned} \quad (6)$$

Similarly, the ZAMO-relative energy density is

$$\begin{aligned} \mathcal{E}(n) &= \frac{1}{8\pi} [E(n)^2 + B(n)^2] \\ &= \frac{1}{8\pi} \frac{Q^2}{\Sigma^2} \left(\frac{(r^2 + a^2)^2 + a^2 s^2 \Delta}{(r^2 + a^2)^2 - a^2 s^2 \Delta} \right). \end{aligned} \quad (7)$$

The 3-volume element, dV , and the 2-volume element, dA , at fixed r and for $\theta \in [0, \pi]$ coordinate are needed in the following

$$\begin{aligned} dV &= \sqrt{g_{rr}g_{\theta\theta}g_{\phi\phi}} dr d\theta d\phi \\ &= \sin \theta \sqrt{\Sigma[(r^2 + a^2)^2 - a^2 s^2 \Delta]} / \sqrt{\Delta} dr d\theta d\phi, \\ dA &= \sqrt{g_{\theta\theta}g_{\phi\phi}} d\theta d\phi \\ &= \sin \theta \sqrt{(r^2 + a^2)^2 - a^2 s^2 \Delta} d\theta d\phi. \end{aligned} \quad (8)$$

In order to make contact with the progenitor NS magnetic field, we compute the magnetic flux through the northern hemisphere of a sphere of radius r using Equations (5) and (8)

$$\Phi(B) = \int_0^{2\pi} \int_0^{\pi/2} B(n)_{\hat{r}} dA = \frac{2\pi a Q}{r}. \quad (9)$$

If we introduce the redshift between the ZAMO frames and the stationary observers at asymptotic infinity, the lapse function ($\alpha = \Delta^{1/2} s / (g_{\phi\phi})^{1/2}$), the integrated field energy is

$$I = \int \alpha \mathcal{E}(n) dV = 2\pi \int_{r_+}^{\infty} dr \int_0^{\pi} d\theta \mathcal{E}(n) \Sigma \sin \theta. \quad (10)$$

It results after the integration over the θ coordinate to

$$I = I_1 + I_2, \quad (11)$$

where

$$\begin{aligned} I_1 &= - \frac{Q^2}{a^2} \int_{r_+}^{\infty} dr \frac{(r^2 + a^2)}{(2Mr - Q^2)} \Psi \left(\sqrt{\frac{a^2 \Delta}{(r^2 + a^2)^2 - a^2 \Delta}} \right) \\ I_2 &= \frac{Q^2}{2a^2} \int_{r_+}^{\infty} dr \left[\frac{(2(r^2 + a^2) - (2Mr - Q^2))}{(2Mr - Q^2)} \right] \Psi \left(\frac{a}{r} \right) \end{aligned} \quad (12)$$

with $\Psi(x) \equiv x \arctan(x)$. I_1 is the stored energy in the electric field and I_2 is the stored energy in the magnetic field. These integrals can be approximated in the limit $(a/M)^2 \ll 1$, $(Q/M)^2 \ll 1$ and $|Qa|/(M)^2 \ll 1$, by $I_{\text{approx}} = \mathcal{E}(\text{magn}) + \mathcal{E}(\text{elec})$,

$$\mathcal{E}(\text{elec}) \approx \frac{Q^2}{4M} + \frac{Q^4}{16M^3} + \frac{a^2 Q^2}{32M^3} + \dots$$

$$\mathcal{E}(\text{magn}) \approx \frac{a^2 Q^2}{32M^3} + \dots \quad (13)$$

3 COLLAPSE OF THE NEUTRON STAR

In this section, we discuss the assumptions used in our study of neutron star collapse in the field shedding model.

- (i) The initial B field is approximately dipolar at the NS surface.
- (ii) The flux stays frozen into the superconducting fluid of subatomic particles as it collapses through the horizon.
- (iii) The mass and angular momentum are approximately conserved during the collapse.

One problem with analyzing these assumptions with numerical simulations is that the fundamental physics is not well understood. The final result is driven by assumptions of the numerical code and imposed expediences used to avoid complicated physics. Thus, there are a variety of disparate outcomes. As mentioned in the introduction, the flux shedding model of FRBs and GRBs in Hanami (1997); Falcke and Rezzolla (2014); Zhang (2014) take place in a Schwarzschild background and the authors identify the magnetic flux as “hair”. However, if the progenitor NS has a magnetic flux, Φ_{NS} , through the northern hemisphere, by Equation (9) and assumptions (2) and (3), above, the NS with angular momentum per unit mass, a_{NS} , and mass, M_{NS} , can, in principle, collapse to a KNBH defined by

$$Qa = \frac{\Phi_{NS}}{2\pi r_+}, \quad a = a_{NS}, \quad M = M_{NS}, \quad (14)$$

without violating any principles of relativity. Thus, there is no “hair” to shed.

It was proposed in Lyutikov and McKinney (2011), that pair creation similar to that in the standard pulsar model will continue to seed the magnetosphere during collapse and source the poloidal field eternally after the black hole forms. Thereby transferring the field source from the NS matter to an external magnetospheric pair plasma. The steady state is a “boot-strapping” model in which the pairs create the electromagnetic field which in turn create the pairs. However, force-free simulations of the collapse of a rotating NS found that the magnetic flux is shed during collapse due to reconnection (Lehner et al. 2012). Also, using a variety of assumptions both Hanami (1997) and Dionysopoulou et al. (2013) showed an electromagnetic pulse that accompanies the shedding of the magnetic flux before the current source penetrates the event horizon. However, the background metric is not altered by the charge and angular momentum of the collapsing matter, so it does not represent the allowed KN solution in which magnetic flux shedding need not occur.

There is simply not enough known about the physics to resolve this issue at present. However, we seek a subset of solution space that circumvents the objection posed by Lyutikov and McKinney (2011). We consider the notion of a death-line for pulsars (Chen and Ruderman 1993). The idea is that the energy available to produce electron-positron pairs is the voltage drop across magnetic field lines, ΔV , which scales like $\Delta V \sim B/P_{NS}$ as a consequence of the frozen-in condition in a rotating magnetosphere (where

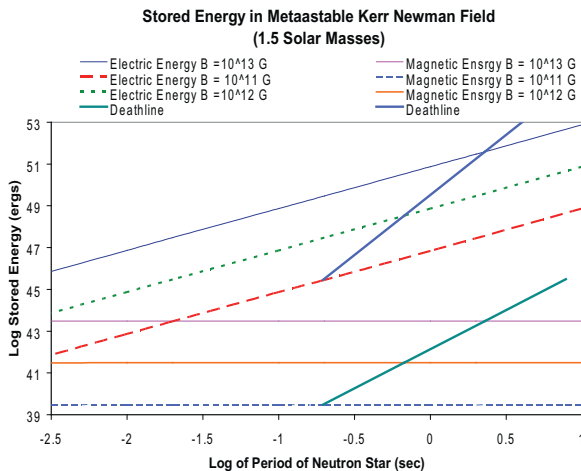


Figure 1. The stored electric and magnetic energy of the metastable Kerr-Newman black hole as a function of the progenitor neutron star, B_{NS} and P . The pulsar death-lines are superimposed based on a dipolar NS magnetic field. The stored energy increases for supramassive progenitors with larger radii.

P_{NS} is the pulsar rotational period). So for any pair creation mechanism, as B decreases or P_{NS} increases, there will be insufficient energy to initiate the pair creation that seeds the magnetosphere with plasma. There will be no observable pulsar. Particle-in-cell simulations of rotating field aligned dead pulsars indicate that the magnetic field is not in the force-free configuration, as assumed in the simulations of Lehner et al. (2012), but is in a dipolar configuration (Chen and Beloborodov 2014). This agrees with our first assumption in this section. It is proposed that even though B/P_{NS} increases during the collapse, by assumptions (2) and (3), the fact that there is no pre-existing plasma-filled magnetosphere will not allow the change in ΔV to effectuate plasma filling of the magnetosphere before the subatomic fluid passes out of causal contact. Thus, a KNBH might be able to form, but likely for only a brief instant as we discuss below.

4 THE KERR-NEWMAN METASTABLE STATE

As the superconducting fluid pulls its magnetic flux inward during the collapse, a charge separation occurs. The faster rotation and larger B implied by assumptions (2) and (3) create a cross field potential, ΔV , the same effect described above in the pair creation discussion above. The difference is that within the dense subatomic material there are numerous collisions that allows charge to separate instantaneously across the B field in order to keep the plasma frozen-in (the unipolar inductor affect) (Punsly 2008). This process proceeds promptly regardless of the tenuous pair plasma in the magnetosphere (which is unable to cross the field lines). Thus, the dense subatomic fluid is likely to pass within the event horizon with its magnetic flux frozen-in, unimpeded by the physics of the tenuous magnetospheric plasma. The increase of the intrinsic charge density of the collapsed matter implies that charge is ejected outward by the unipolar

inductor (i.e., the unipolar driven current). The net result is that the local physical process will increase the magnitude of the total charge of the collapsed object. The same physics causes a neutron star to have a net charge in a pulsar (Ruderman and Sutherland 1975). The charge that is added to the subatomic fluid as a consequence of the charge separation driven by unipolar induction during the collapse increases the charge from the NS value to that of the KNBH in Equation (14), $Q_{BH} \sim [(MR_{NS})/(a^2)]Q_{NS}$.

The increase in the charge of the subatomic fluid described above results in a major difference between the NS electromagnetic field and the KNBH electromagnetic field. The NS electromagnetic field is magnetic ($E^2 - B^2 < 0$), meaning that there exist local physical observers that can see the field as purely magnetic, but there is no observer that can see a purely electric field. Conversely, by Equation (6), the KNBH electromagnetic field is electric everywhere (Punsly 1998). Since there is an unscreened mono-polar electric field, the KNBH is subject to electric discharge. It is the electric discharge that sheds the magnetic field by Equation (14). Note that in the case of exactly zero angular momentum, the Schwarzschild black hole, there is no solution for a magnetic flux source inside of the event horizon that is allowed in general relativity and the no hair theorem is the appropriate interpretation of the flux shedding. In spite of the argument in the previous section, with our current level of understanding of the relevant microphysics, one can not say if it is possible for the discharge to take place before the black hole forms. However, based on the discussion of unipolar induction above, we consider this unlikely.

In this letter, we consider a prompt discharge of the KNBH, i.e., it is a metastable configuration that occurs as part of the collapse. We plot the stored electric and magnetic energy in Figure 1 using Equation (13). We assume a low centrifugal force configuration of the progenitor NS with collapse to a BH occurring once the Chandrasekhar limit is exceeded by unspecified interactive processes with the surrounding medium, $M = 1.5M_{\odot}$. A supramassive NS progenitor as in Falcke and Rezzolla (2014); Zhang (2014) would have a larger mass $M \gtrsim 2.5M_{\odot}$ and a larger progenitor radius. The stored energy is plotted as a function of the NS magnetic field strength at the pole, B_{NS} , in the dipolar approximation. The assumed radius of the NS is 12 km. Note that the magnetic energy is independent of the rotational period for small a/M . The electric energy increases for smaller a , if B_{NS} at the neutron star pole is held fixed, as a consequence of Equation (13). The relevant death-line from Chen and Ruderman (1993) is the one for a dipolar magnetic field that is assumed here. They noted that other magnetic field configurations can move the death-line to the right, however that would be inconsistent with the assumptions of the previous calculations in this letter. For slow rotating NS progenitors there is an allowed collapsed state KNBH solution for parameters to the right of the death-line where pair production is suppressed. The power of the FRBs can be explained for $B_{NS} \gtrsim 10^{12}$ G and periods longer than 1 second. The rapidly rotating (such as as supramassive) progenitors require a large centrifugal force to support them and lie to the left of the death-line. It is also evident that the stored electric energy exceeds the magnetic energy. We estimate $\mathcal{E}(\text{magn})$ and $\mathcal{E}(\text{elec})$ in Equation (13) in terms of the progenitor NS values in order to make contact with

Equation (1) of Zhang (2014),

$$\begin{aligned}\mathcal{E}(\text{magn}) &\approx \frac{3}{16} \frac{R_{NS}}{M} \left[\frac{1}{6} B_{NS}^2 R_{NS}^3 \right] \approx \frac{1}{8} \left(\frac{a}{M} \right)^2 \mathcal{E}(\text{elec}) \\ \mathcal{E}(\text{elec}) &\approx \left(\frac{M}{a} \right)^2 \frac{3R_{NS}}{2M} \left[\frac{1}{6} B_{NS}^2 R_{NS}^3 \right].\end{aligned}\quad (15)$$

The magnetic field energy computed in Zhang (2014) is captured in the last term in square brackets.

The logical question is whether this stored energy can be extracted. Ostensibly, since the energy is electromagnetic it can be radiated near the speed of light and can avoid being swallowed by the black hole. We explore if there is a fundamental general relativistic reason that the energy cannot be radiated by considering the irreducible mass. The mass of the black hole decomposes into its rest mass, reducible mass and irreducible mass (Christodoulou and Ruffini 1971):

$$M^2 = \left(M_{\text{irr}} + \frac{Q^2}{4M_{\text{irr}}} \right)^2 + \left(\frac{Ma}{2M_{\text{irr}}} \right)^2. \quad (16)$$

The irreducible mass cannot be extracted from the black hole. The remainder, the reducible mass, $M_{\text{red}} = M - M_{\text{irr}}$, can be extracted in principle. From Equations (13) and (16), in the limit of small Q/M and a/M ,

$$M_{\text{red}} = \mathcal{E}(\text{elec}) + \mathcal{E}(\text{magn}) + \frac{1}{8} \frac{a^2}{M} + \frac{5}{128} \frac{a^4}{M^3} + \frac{1}{32} \frac{Q^2 a^2}{M^3} + \dots, \quad (17)$$

The electromagnetic stored energy is extractable. The last three terms in Equation (17) appear to represent the rotational energy. The first two of these are the rotational energy of a Kerr black hole. There is an extra term, $\frac{1}{32} \frac{Q^2 a^2}{M^3}$, that is not present in the Kerr geometry and is not part of the stored field energy integral in Equation (13). It appears to a relativistic correction to the first term of the rotational energy that is due to the leading order contribution to the electromagnetic energy, the charge contribution to the total energy, $\frac{1}{4} \frac{Q^2}{M}$.

5 CONCLUSION

In this paper, it was proposed that the magnetic field shedding model of FRBs can be understood self-consistently if one includes a metastable KNBH state after the collapse from a progenitor NS. The magnetic flux is shed by electric discharge **and not because of** a no hair requirement. The analysis of the last section resolves some issues and raises more questions. For NS progenitors with $P_{NS} > 1$ sec, the pulsar death-line indicates that collapse to a KNBH should occur without any influence from pair creation in the magnetosphere. This state can discharge electrically thereby reproducing the magnetic field shedding in the FRB and GRB models (Hanami 1997; Falcke and Rezzolla 2014; Zhang 2014). The argument has a range of applicability for $10^{11} \text{G} < B_{NS} < 10^{13} \text{G}$.

The vast majority of pulsars are likely dead and are generally of low luminosity and not detected. However, it is believed that spin up accretion in a binary system can recycle dead pulsars at a rate $\approx 1.5 - 3.0 \times 10^{-3} \text{yr}^{-1}$ (Deshpande et al. 1995). However, it is known that accretion can also spin down pulsars (Chakrabarty et al. 1997). This spin-down will increase the mass of the NS and decrease centrifugal force. For a heavier NS, centrifugal force

might be required to prevent gravitational collapse and spin down accretion might initiate catastrophic collapse to a BH. The catastrophic collapse rate of dead pulsars would likely be the same order of magnitude as the recycle rate of dead pulsars, $\approx 1.5 - 3.0 \times 10^{-3} \text{ yr}^{-1}$, which agrees with the FRB birth rate, $10^{-3} \text{ gal}^{-1} \text{ yr}^{-1}$. The reducible mass associated with the magnetic field in Equation (17) would be manifest as an electromagnetic pulse that has been proposed to power the FRB either from high energy pair plasma in a shock wave or by coherent emission from particle bunching in the strong electromagnetic wave (Falcke and Rezzolla 2014; Zhang 2014). From Figure 1, the metastable KNBH low spin state has a stored electric energy that far exceeds the stored magnetic energy. Being longitudinally polarized, the release of this energy is not directly into electromagnetic waves. It has been proposed (and extensively modeled) that the reducible mass in Equation (17) is extracted by a fireball of pair plasma in models of GRBs with afterglow (Ruffini et al. 2001). The energy of FRB 150418 and its afterglow is $\sim 10^{49} - 10^{50}$ ergs, consistent with the stored electric energy in Figure 1 (Keane et al 2016; Zhang 2016). It may also be that FRB 150418 represents a different class of FRB and this is a numerical coincidence (Keane et al 2016).

For the supramassive NS invoked in Falcke and Rezzolla (2014); Zhang (2014) the death-line argument cannot be used to validate this scenario since they require $P_{NS} < 0.1$ s in order to provide adequate centrifugal support. Force-free simulations indicate that the flux will be shed by prompt reconnection and no KNBH metastable states form (Lehner et al. 2012). Although the “electric field pruning” that was implemented might render such a simulation incapable of finding KNBHs and their “electric” magnetospheres. In any event, these results raise the question of whether there is any observational evidence of highly magnetized black hole magnetospheres associated with stellar mass black holes. There is a major prediction of such a scenario, the magnetosphere will produce a tenuous outflow of electron-positron plasma at a highly relativistic velocity in the form of a jet or wind (Blandford and Znajek 1977; Lyutikov and McKinney 2011). We find no direct observations of highly relativistic winds from black holes, yet there are numerous observations indicating non-relativistic or mildly relativistic jets and ejections. The two most publicized examples of highly superluminal motion have not stood the test of time and better data. The direct observations of component motion in Galactic BHs show subluminal or slightly superluminal motion, not the highly superluminal motion expected from black hole driven magnetically dominated outflows. For example, the discrete ejecta in GRO J1655-40 are no longer considered to be highly superluminal and are now believed to move $\sim 0.37c$ (Foellmi et al 2006). The parallax determined distance measurement to GRS 1915+105 is $8.6^{+2.0}_{-1.6}$ kpc (Reid et al. 2014). This changes the intrinsic velocity of the discrete ejections to $0.65c - 0.81c$. The parallax measurements and the jet asymmetry arguments in Ribo et al. (2004) indicate that the compact jet in GRS 1915+105 propagates with $0.07c < v < 0.37c$. The best case for moderately relativistic ejection in a Galactic BH is a Lorentz factor of 2 in one of the flares of XTE J1550-564, the other flares are considerably slower (Orosz et al. 2011). This result, even though it is not the highly relativistic speed expected from an event

horizon magnetospheric outflow, still depends on a distance estimate that has not been verified by a parallax observation. One could argue that the slow outflow velocities are the manifestation of mass loading from the enveloping medium (Murguia-Berthier et al. 2014). But, interferometric observations of ejecta in Galactic BHs agree with radio light curves - the speed \approx constant with no abrupt luminosity change near the time of ejection (Dhawan et al 2000; Punsly & Rodriguez 2013). Baryon loading (if it occurs) seems to occur at the source. Yet, the putative event horizon magnetosphere is baryon poor. The observations seem to indicate that the event horizons of Galactic black holes are either weakly magnetized or non-magnetized. Apparently, any significant magnetization that they had was a brief transient or was shed during formation.

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